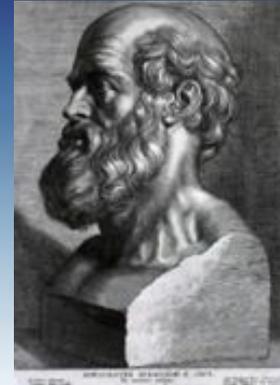


Data to Insights and Actions: Enabling Evidence-Based Healthcare

Eric Horvitz
Microsoft Research

NITRD Symposium
Washington DC
February 2012

A Long-Term Pursuit



Hippocrates (c. 460 B.C. - c. 370 B.C.)

- On diseases, make a habit of two things—to help, or at least to do no harm.

Epidemics, in Hippocrates, trans. W. H. S. Jones (1923), Vol. I, 165.

- ...it is worth learning from everyone; for people do not discover these by reasoning but by chance, and experts not more than laymen.

Affections, in Hippocrates, trans. P. Potter (1988), Vol. 5, 69. Littré VI, 254.

*Attaining dream of evidence-based reasoning
through advances in computer science.*

Fueling Pursuit of the Dream

Significant advances made possible via long-term funding by prescient federal agencies

- Critical NIH, NSF, ONR, DARPA support for decades
- AI in Medicine (AIM) in 1980s → Core CS
 - Ignited veritable revolution in machine intelligence
 - Core advances in context of AIM:
representation, inference, decision making, machine learning for medical applications.



Exciting Times

- ↑ **Learning & reasoning prowess**
- ↑ **Sensing, interaction, ubiquity**
- ↑ **Computation & connectivity**
- ↑ **Data capture → learning, decisions**

Wrestling with a Bottleneck

- ↑ Learning & reasoning prowess
- ↑ Sensing, interaction, ubiquity
- ↑ Computation & connectivity
- ↑ Data capture → learning, decisions



Enabling Evidence-Based Medicine

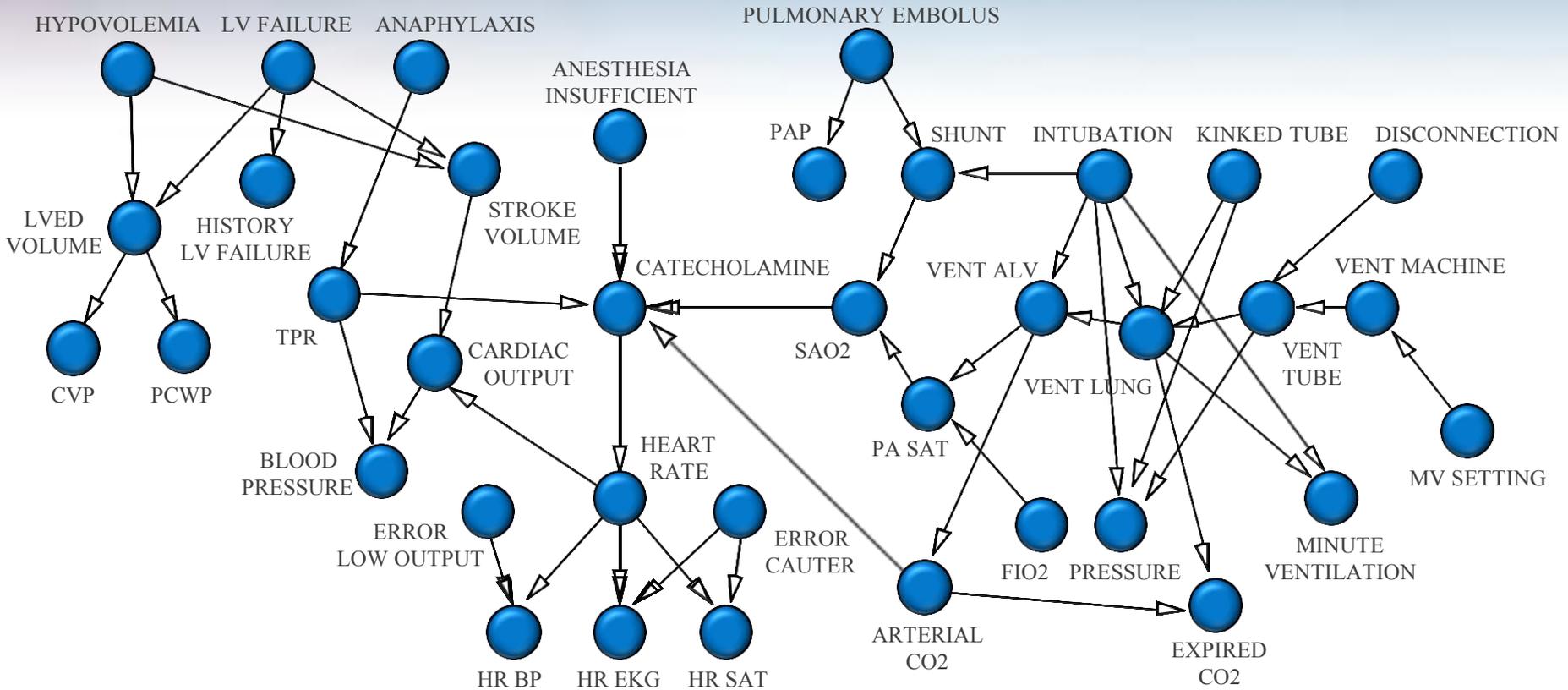
- **Diagnosis, actions, policies**
- **Wellness and prevention**
- **Discovery**

Data capture → **learning, decisions**



Advances in Representation & Reasoning

- e.g., Probabilistic graphical models



(From I. Beinlich, et al)

Expert Knowledge in Decision Support

The image shows a screenshot of a web browser displaying the Microsoft Pregnancy and Child Care website. The browser window title is "Microsoft Pregnancy and Child Care". The navigation bar includes "Home", "Go To", "Find", "Options", and "Help". The main content area features the "Microsoft Health Preview" logo and the title "Pregnancy and Child Care". On the right, there is a "Medical Advisory Board" logo. The central part of the page is dominated by two large, stylized hands, one green and one yellow, reaching towards each other. To the right of the hands, there is a list of five menu items, each with a red arrow icon pointing right:

- What's New**
Click here for this month's highlights in Microsoft Pregnancy and Child Care.
- Library**
To browse through illustrated articles on pregnancy, birth, and early child care, click here.
- Find By Word**
If you know what you're looking for, click here to search the Library by keywords.
- Find By Symptom**
Click here to find useful information in the Library related to children's symptoms.
- Community Center**
Have a story to share? Want to send us mail? Click here to access our community bulletin boards.

Expert Knowledge in Decision Support

Describe the child

in the drop-down boxes at the right. Relevant information will appear below.

Age: Sex:

Complaint:

Localized pain: Can the child localize, or point to, the site of the pain?

- No, unable to localize
- Below the navel to the child's left
- Above the child's navel
- Either of the child's sides
- Below the navel to the child's right
- Above the navel to the child's right
- Above the navel to the child's left
- Don't Know

Start Over

Review

Next>>

Finish

Results so far

Disorder

Relevance

Viral gastroenteritis



Psychosomatic pain



Urinary tract infection

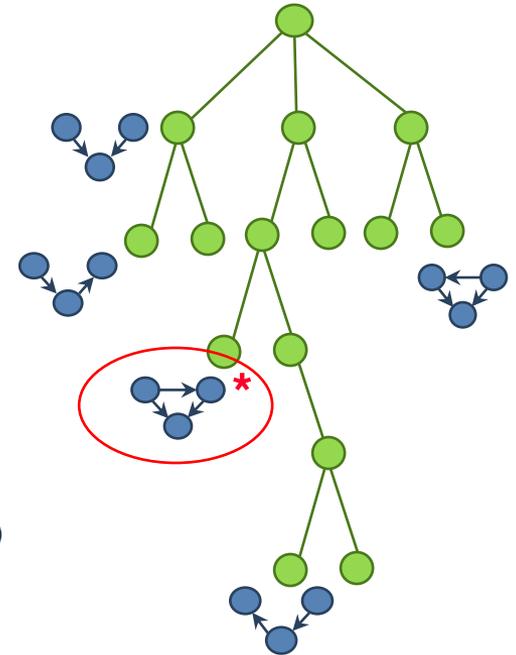
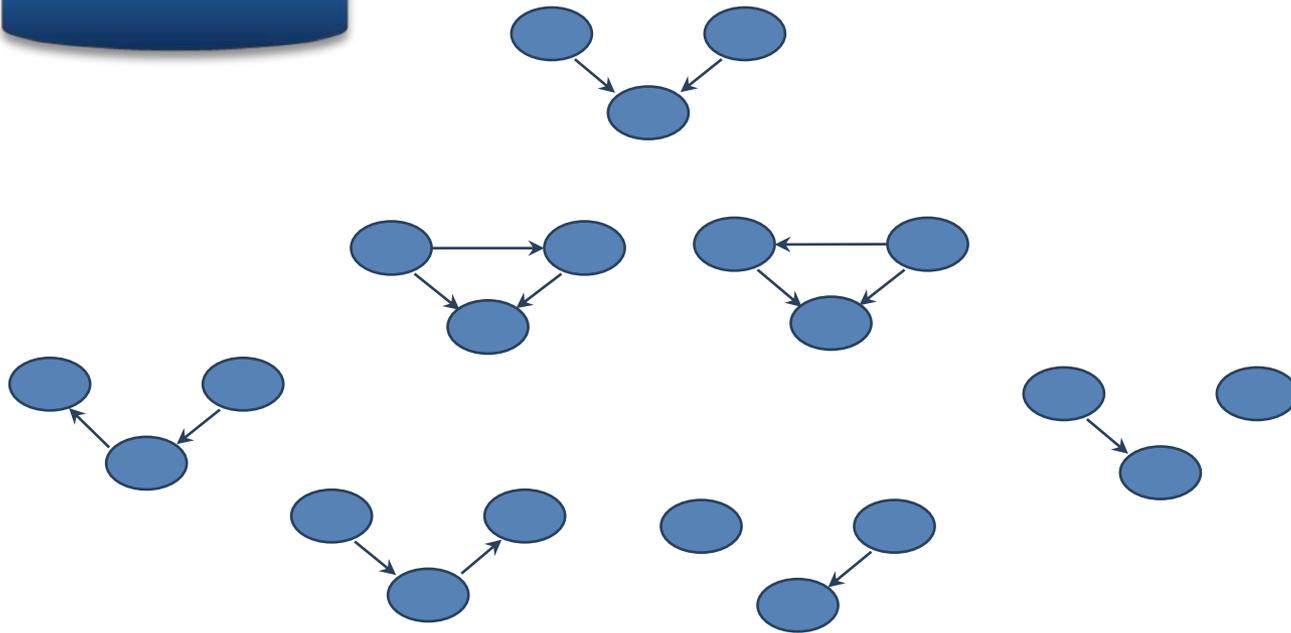


Other



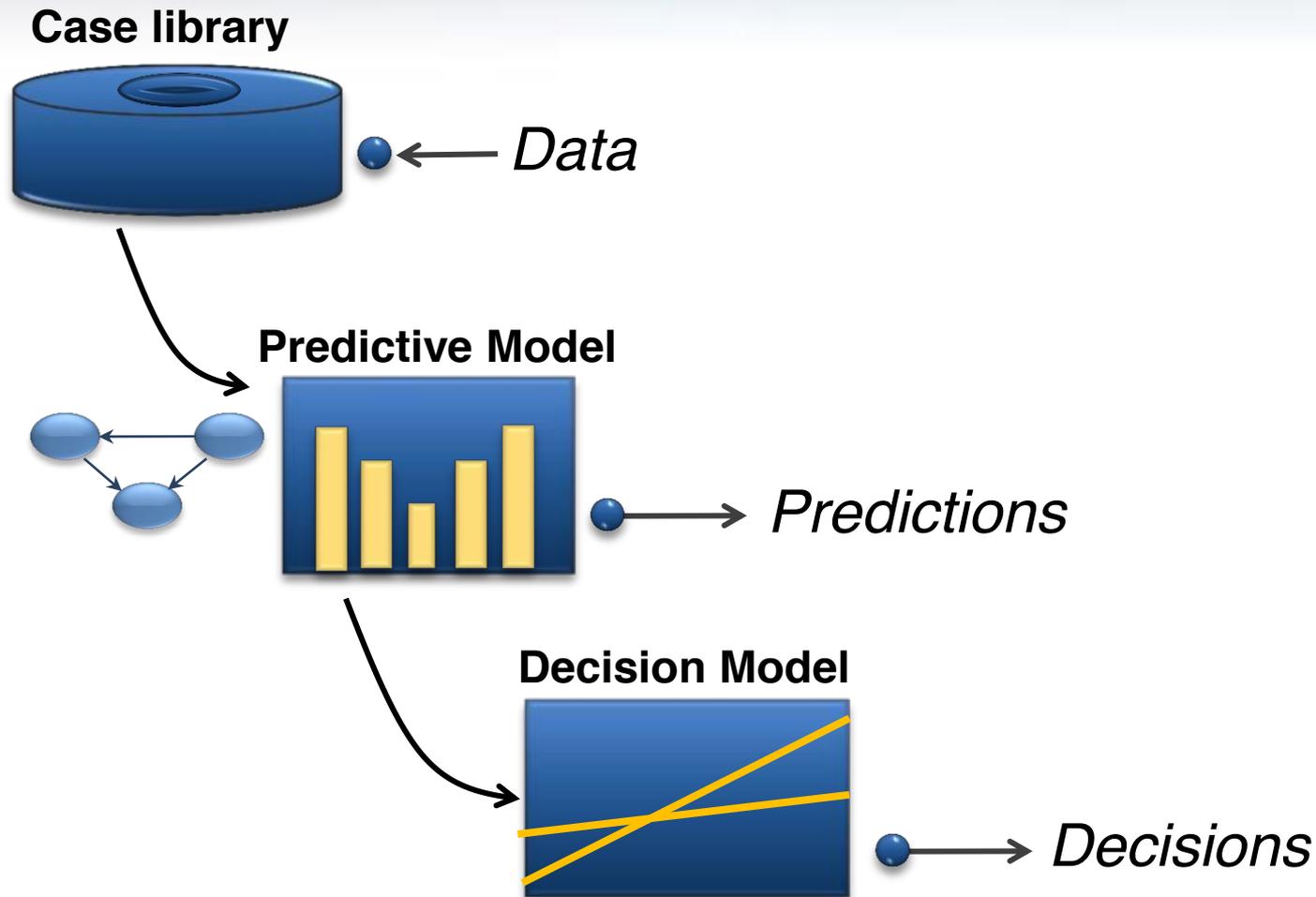
Learning Predictive Models from Data

- New access to large amounts of data
- Procedures for learning predictive models



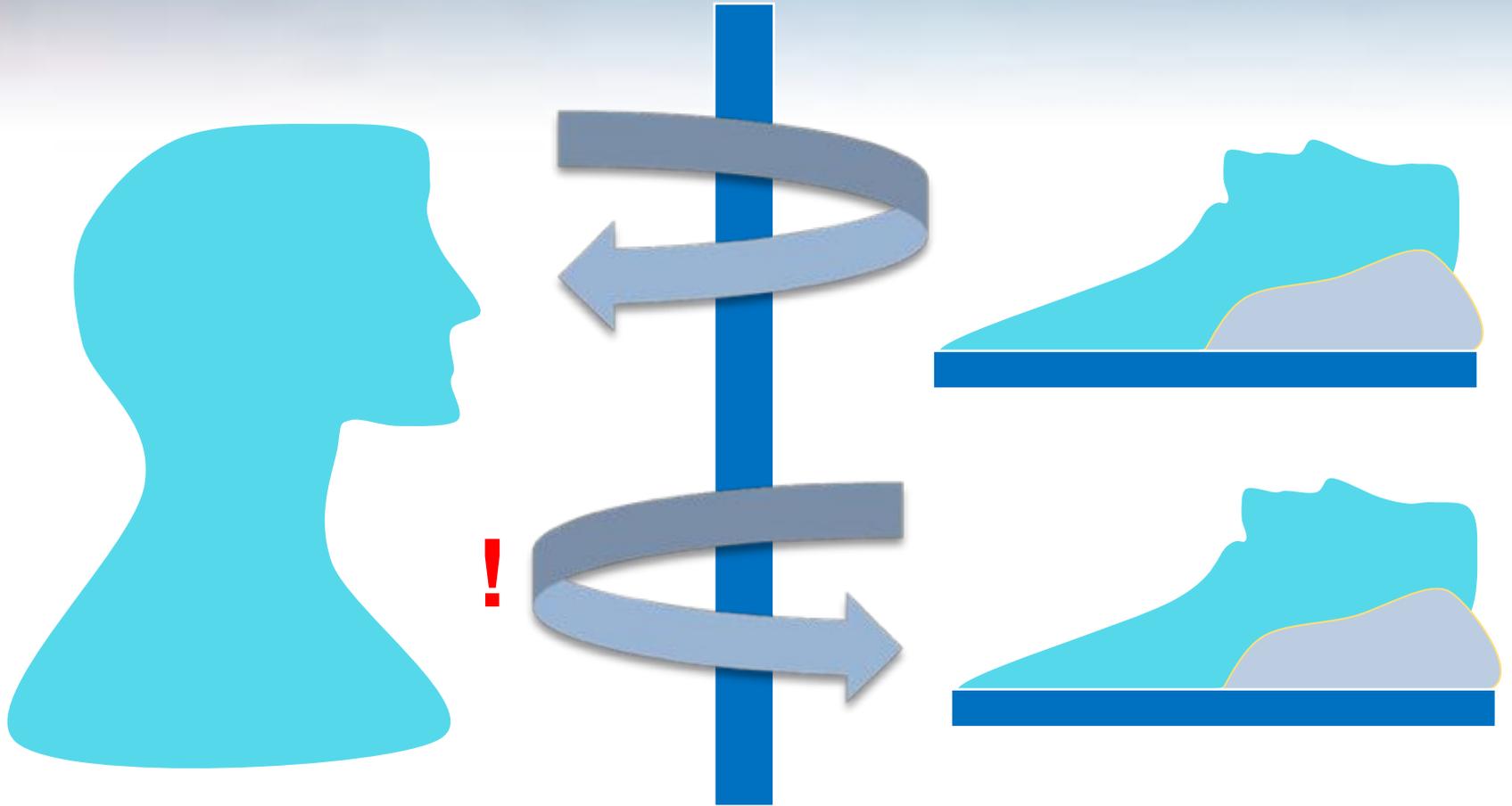
Data → Prediction → Decisions

- Best actions via analysis of costs & benefits under uncertainty



Example:

Reducing Hospital Readmissions



Costly Challenge



THE NEW ENGLAND
JOURNAL of MEDICINE

SPECIAL ARTICLE

Volume 350

Number 14

April 1, 2004

Number 14

2004

Rehospitalizations among Patients in the Medicare Fee-for-Service Program

Stephen F. Jenike, M.D., M.P.H., Mark F. Williams, M.D., and Eric A. Coleman, M.D., M.P.H.

ABSTRACT

Background: Rising rates of rehospitalization have attracted attention from policymakers and a need to improve the frequency and necessary changes.

Methods: We analyzed

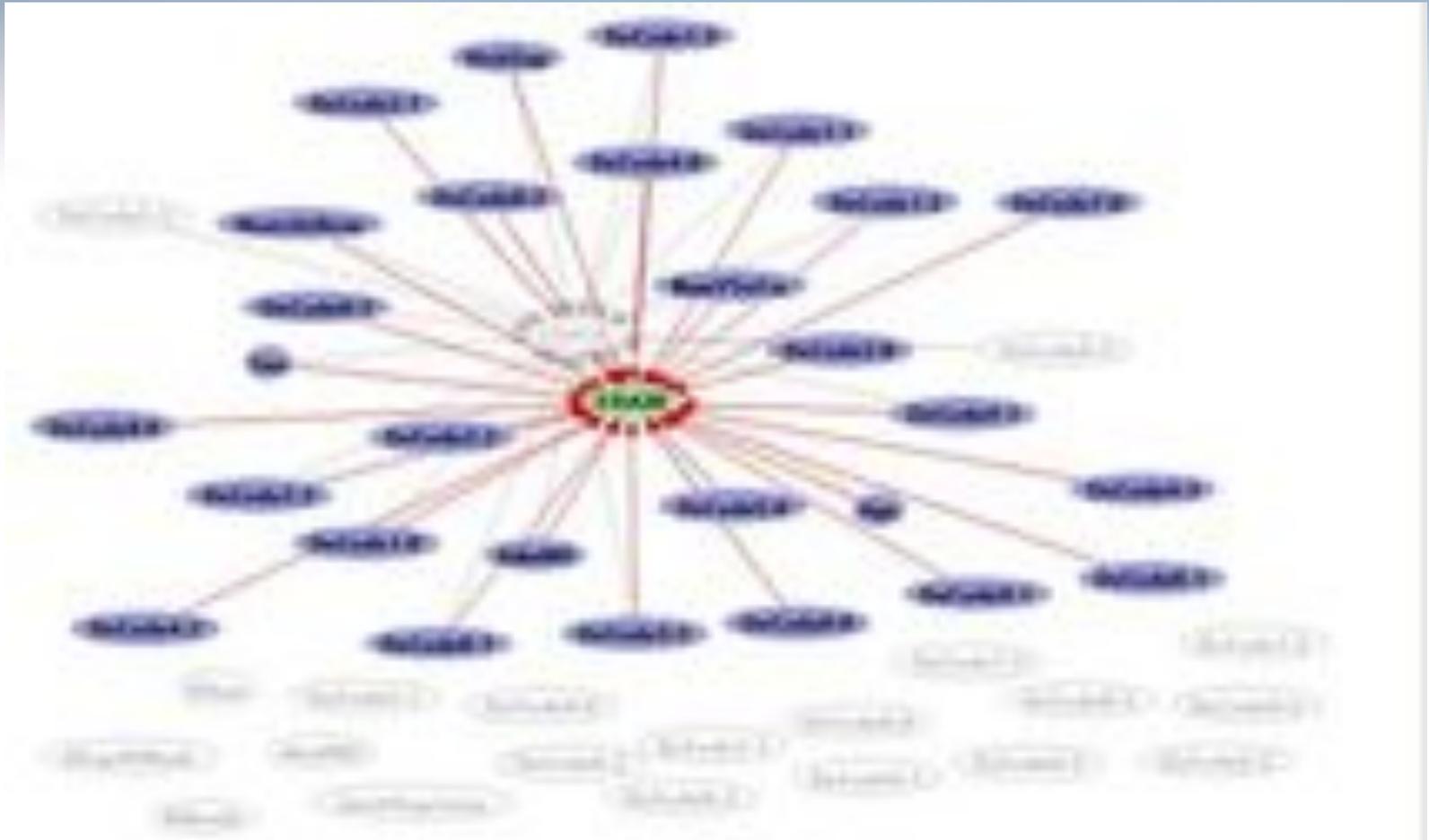
- ~20% within 30 days
- ~35% in 90 days
- ***Estimated cost to Medicare in 2004: \$17.4 billion***

Learning from a Case Library

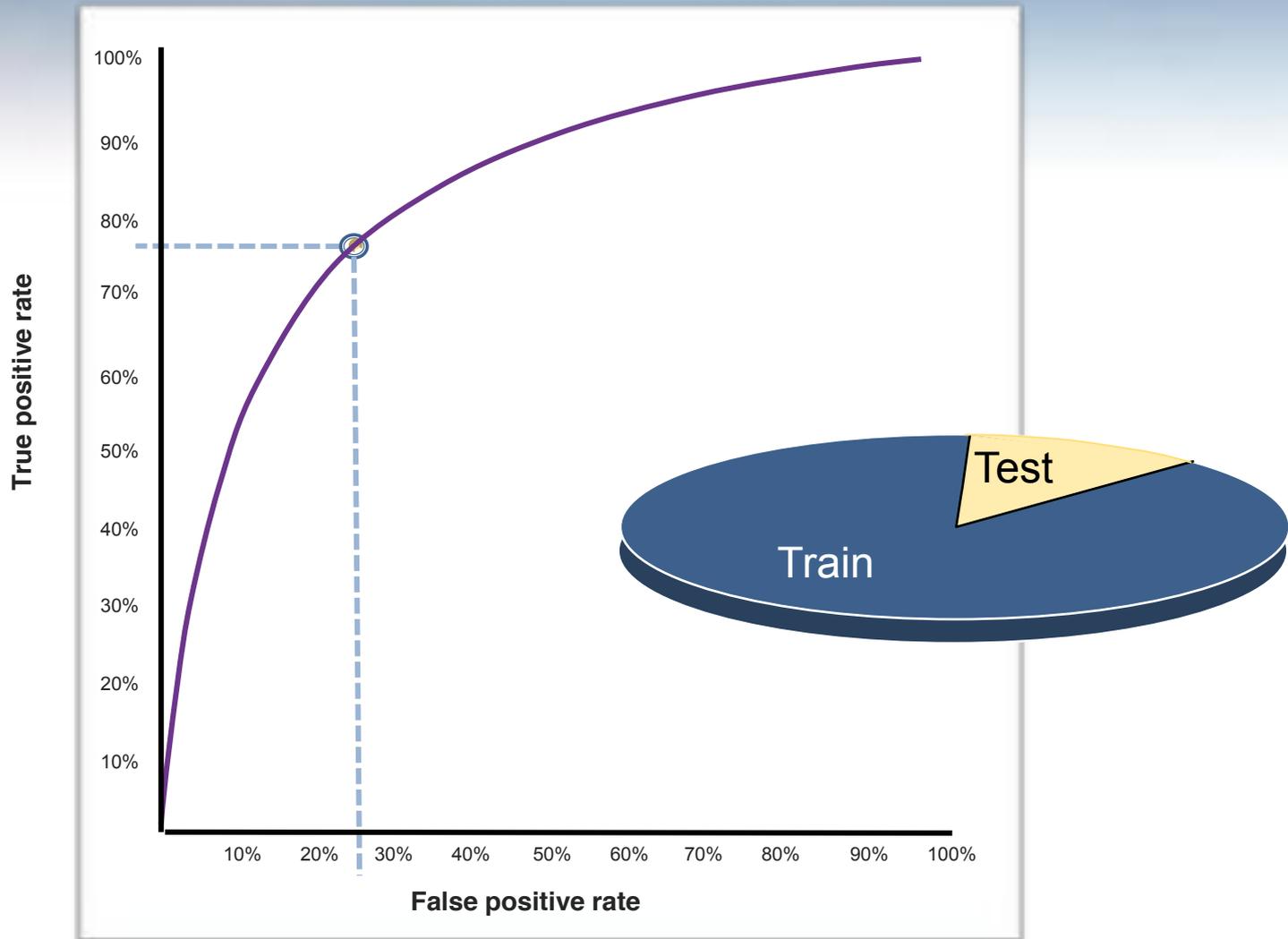
- Washington Hospital Center hospital system (DC)
- All visits during the years 2001 to 2009 (e.g., ~300,000 ED visits)
 - Admissions, discharge, transfer (ADT)
 - Chief complaint in free text
 - Age, gender, demographics
 - Diagnosis codes (ICD-9)
 - Lab results and studies
 - Medications
 - Vital signs
 - Procedures
 - Locations in hospital
 - Admitting and attending MD codes
 - Fees and billing

~25,000 variables considered in dataset

Building a Predictive Model for Readmission



Performance of Classifier for Readmission



Identifying Evidential Relevance

| Weight | Feature description | Frequency |
|---------|---|-----------|
| 0.68398 | Dx0->2 = Excessive vomiting in pregnancy | 0.31% |
| 0.61306 | Dx3->2 = Personal history of malignant neoplasm | 0.28% |
| 0.58281 | Dx0->2 = Heart failure | 0.30% |
| 0.56708 | Dx0->1 = Nephritis, nephrotic syndrome, and nephrosis | 0.09% |
| 0.56649 | Dx3->2 = Heart failure | 0.28% |
| 0.54663 | Complaint sentence contains "suicidal" | 0.17% |
| 0.48415 | Dx1->2 = Disorders of function of stomach | 0.07% |
| 0.47257 | Dx5->0 = Diseases Of The Genitourinary System | 0.15% |
| 0.46136 | Dx0->2 = Chronic airway obstruction, not elsewhere classified | 0.10% |
| 0.44555 | Dx4->2 = Depressive disorder, not elsewhere classified | 0.10% |
| 0.44257 | Stayed 14 hours in the ER | 0.10% |
| 0.43890 | Dx0->1 = Other psychoses | 0.32% |
| 0.43513 | Dx0->0 = Diseases Of The Blood And Blood-Forming Organs | 0.46% |
| 0.42582 | Complaint sentence contains "dialysis" | 0.19% |
| 0.41888 | Dx0->2 = Depressive disorder, not elsewhere classified | 0.27% |
| 0.41302 | Dx1->1 = Nephritis, nephrotic syndrome, and nephrosis | 0.29% |
| 0.38506 | Complaint sentence contains "fluid" | 0.10% |
| 0.37474 | 69 < Age | 9.22% |

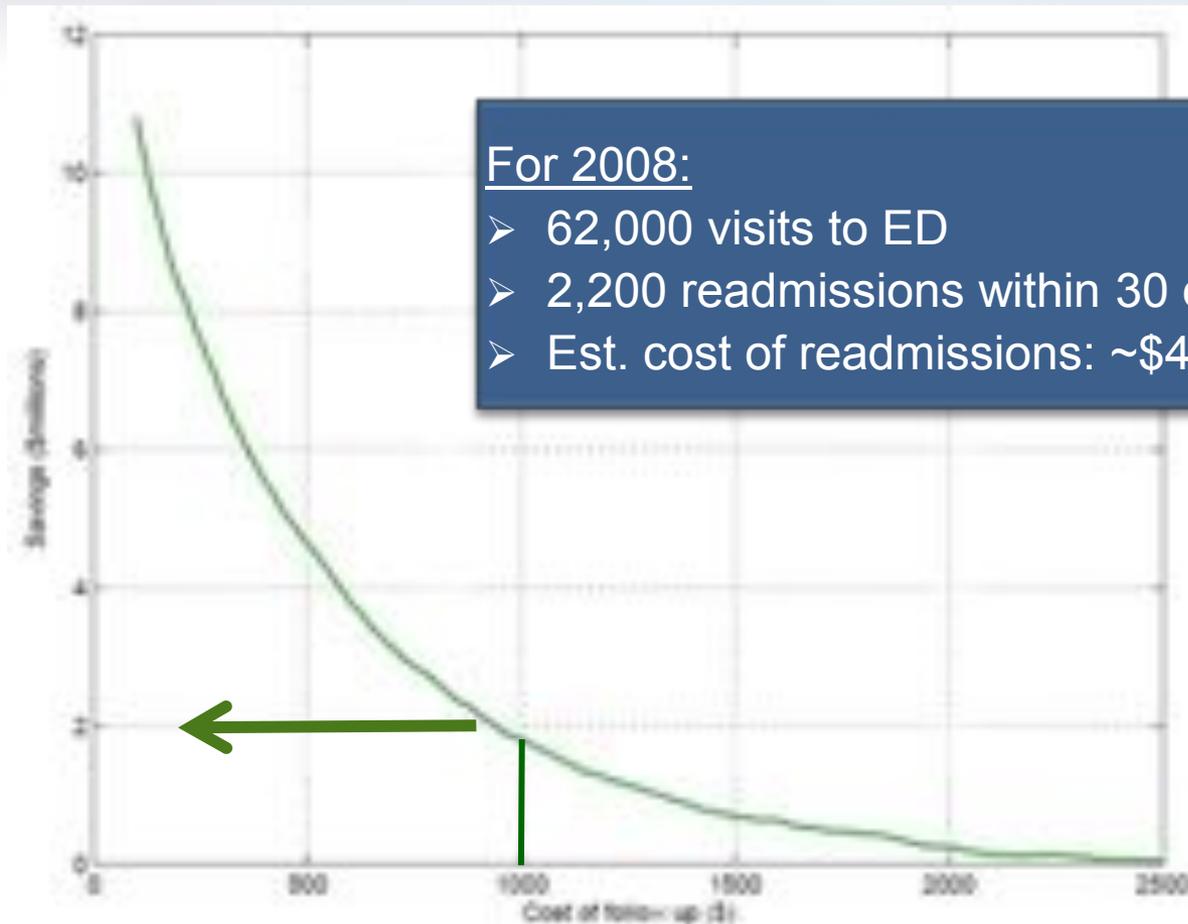
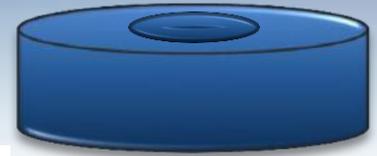
Take Action to Reduce Readmissions?

- Interventions are costly but promise reduced likelihood of readmission
 - Post-discharge care coordination
 - Patient education
 - Scheduled outpatient visits
 - Telemedicine, connected health

Experiences with costs and efficacies reported in literature.

Analysis of Value of Decision System

- Predictive model, 2004-2007, test cases from 2008
- Costs, efficacy from studies

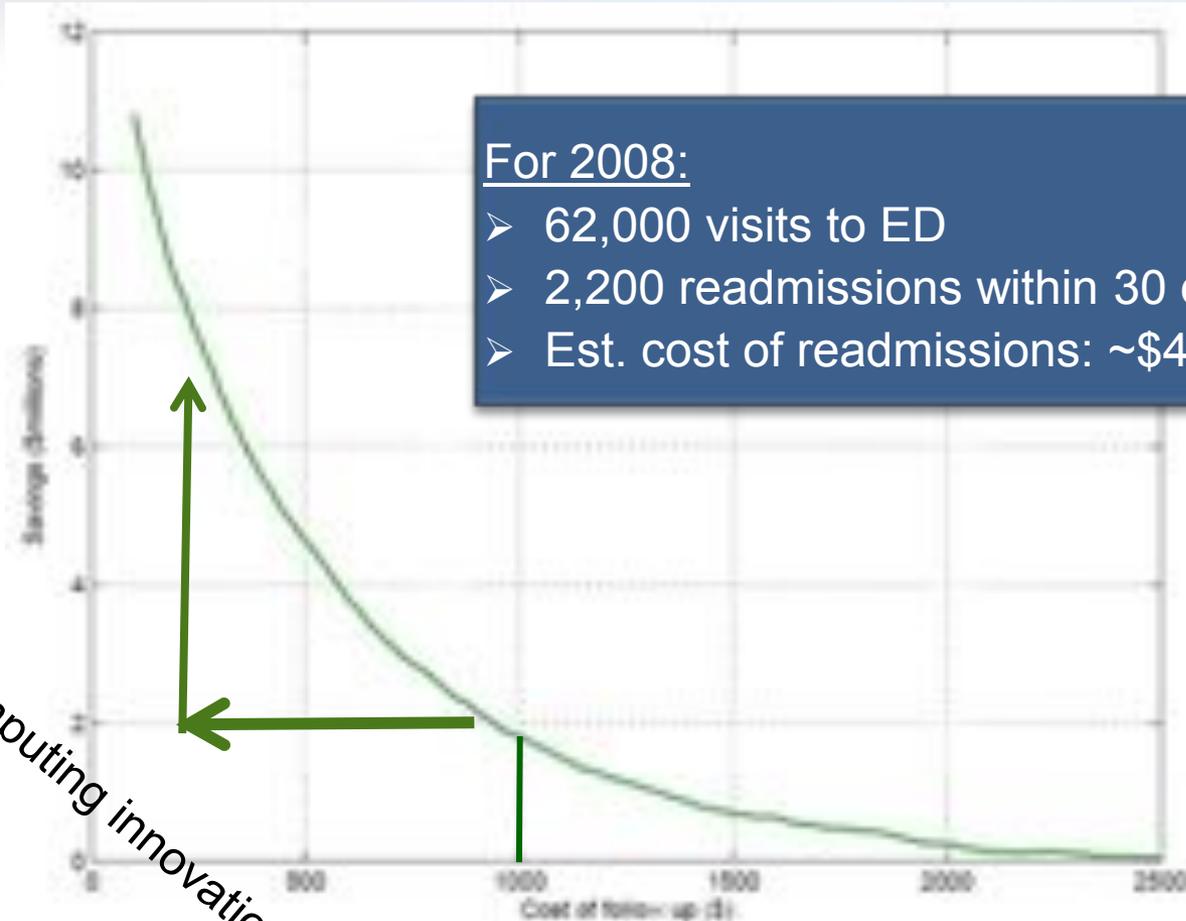


For 2008:

- 62,000 visits to ED
- 2,200 readmissions within 30 days
- Est. cost of readmissions: ~\$44,000,000

Analysis of Value of Decision System

- Predictive model, 2004-2007, test cases from 2008
- Costs, efficacy from studies



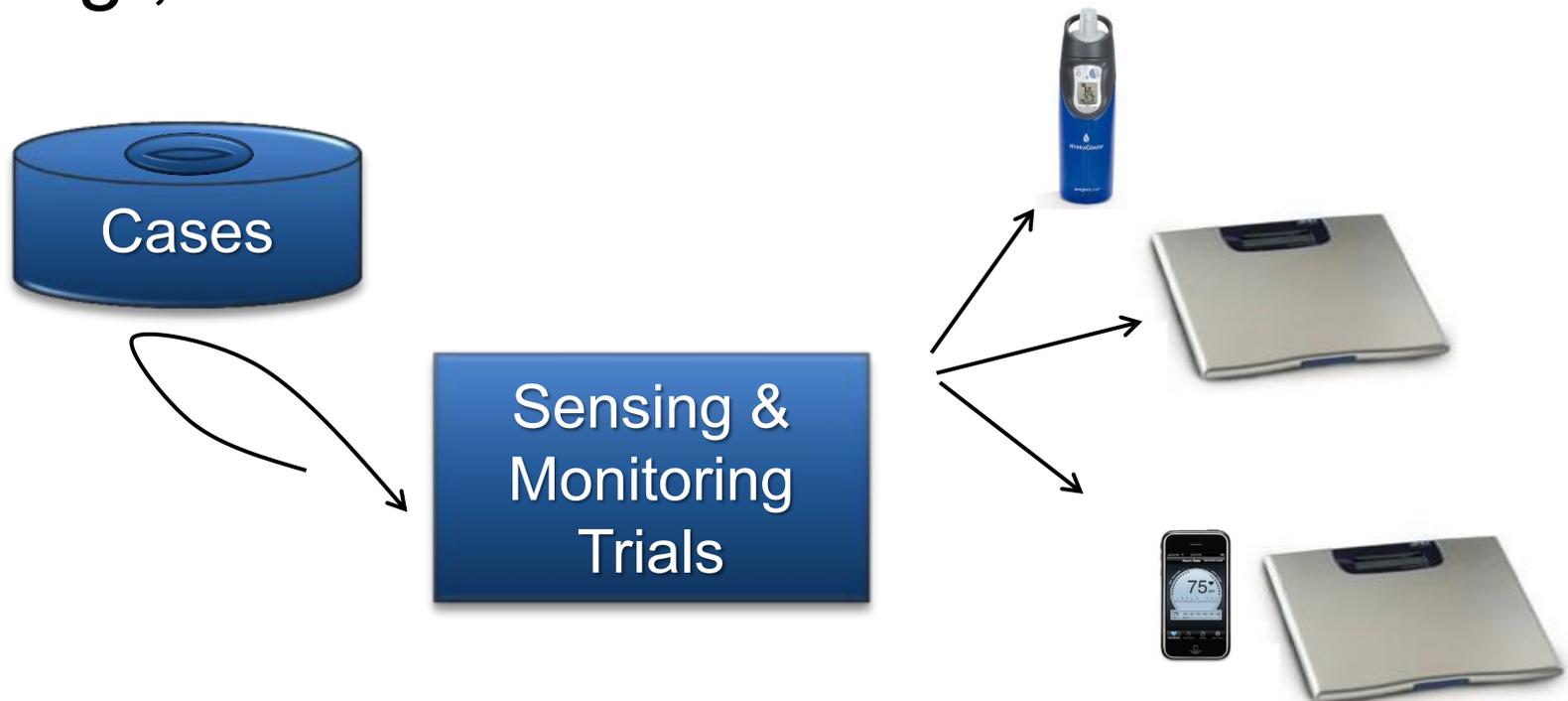
For 2008:

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- 2,200 readmissions within 30 days
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Sensing & computing innovations

Toward Site-Specific Trials

- “Clinical trials” of sensing & intervention strategies
- Local learning cycle for hospital centers, e.g., CHF



Translation: Research to Open World

Readmissions Manager for Microsoft Amalga

Reducing Hospital Readmissions is an Impending Priority

Overview

One in five Medicare inpatients is readmitted within 30 days. The Centers for Medicare and Medicaid Services (CMS) considers 40%-75% of these readmissions to be preventable.

In October 2012, CMS will begin to track readmissions and impose financial penalties on hospitals with higher-than-expected readmission rates for certain conditions. Other payers will certainly follow.

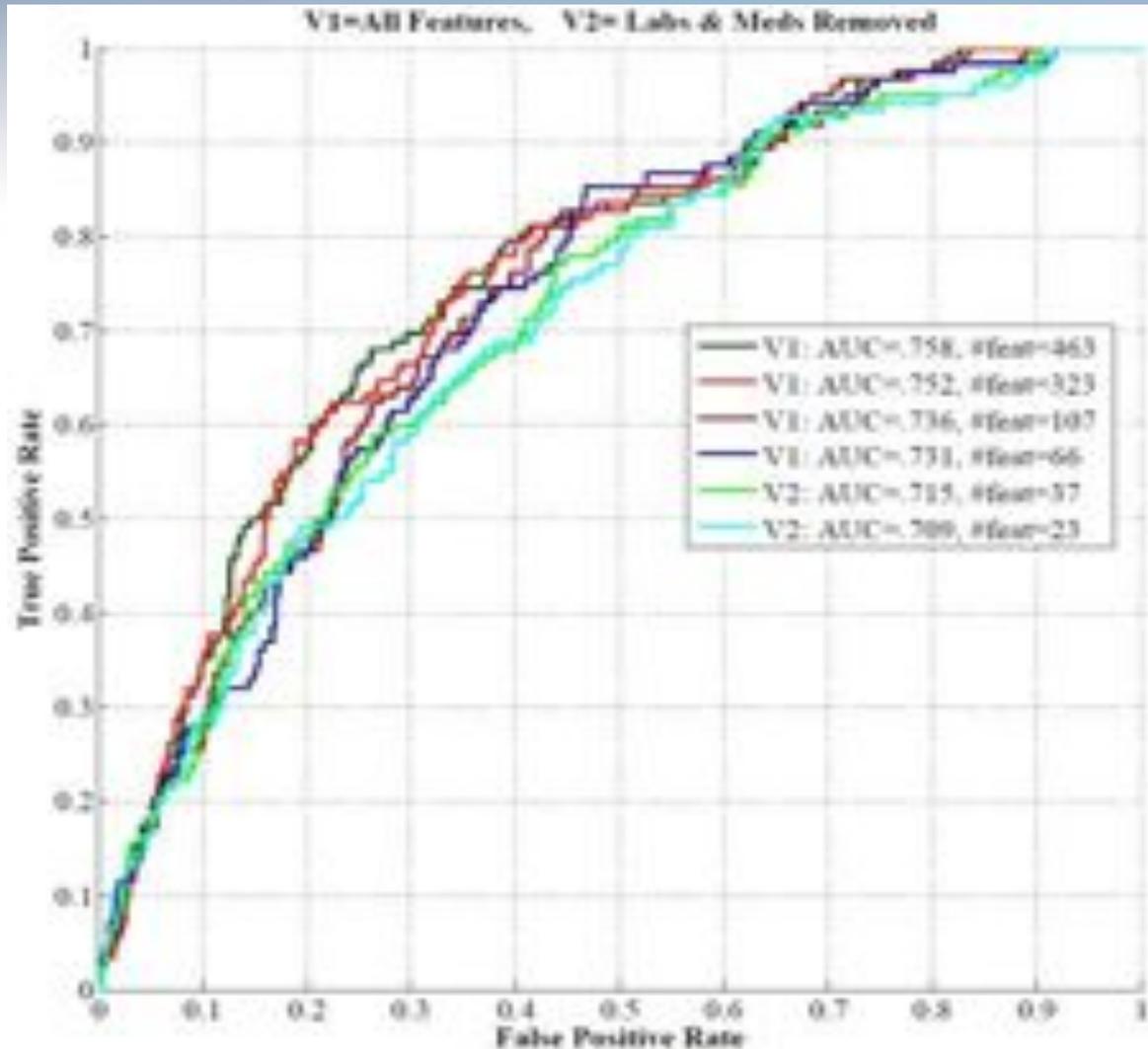
It is clear that hospital admissions and readmissions are becoming a critical parameter for tracking care delivery from both a financial and quality perspective.

Readmissions Manager for Microsoft Amalga is an innovative solution to help organizations address this very important business need.



Readmissions Manager Targets Avoidable Hospital Readmissions

Engineering: Tractability and Tradeoffs



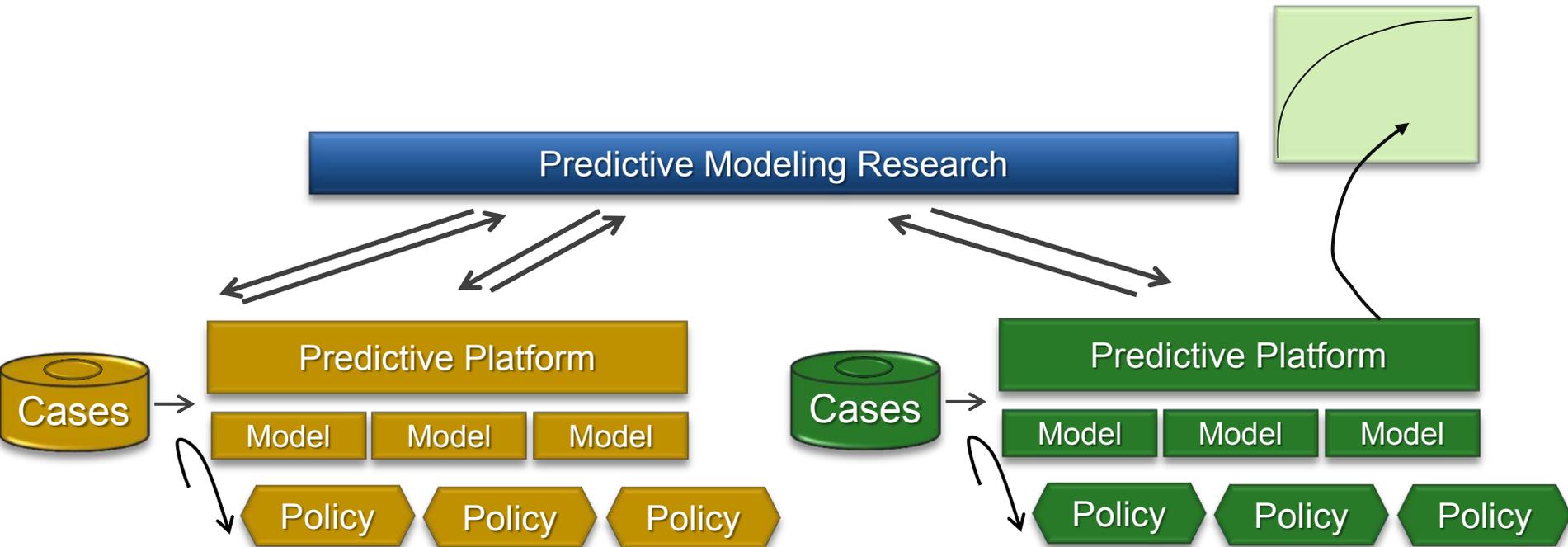
Predictive Platform Goes Live...



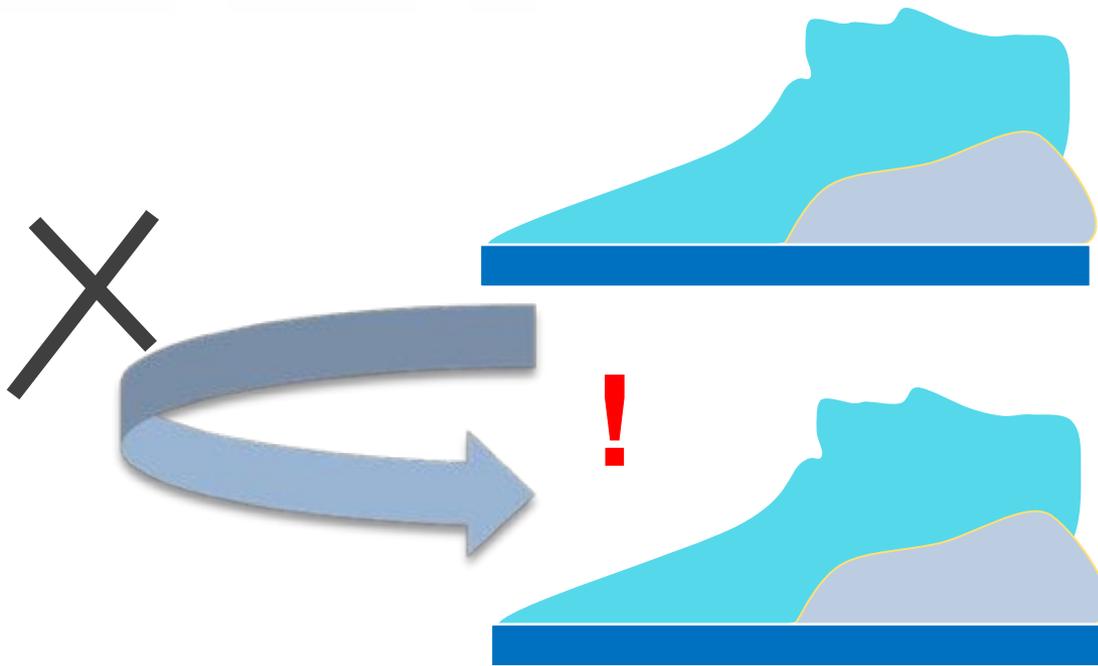
Learning from In-World Application

Automation \longleftrightarrow expert handholding?

- Data differences \rightarrow universal schema
- Local train and test cycle
- Quality assurance



Example: Reducing Medical Errors & Injuries



Challenge of Medical Errors & Injuries

- **Deaths attributed to medical error:**

44,000 - 98,000 / year U.S., preventable errors.

“To Err is Human,” Inst. of Medicine, 2000

- **Adverse medical events:**

13.5% of hosp. Medicare patients, 44% preventable.

Levinson, 2010

- **Costs of errors:**

\$17 to \$29 billion per year in U.S.

Thomas, et al., 1999

Medical Errors & Injuries in the News

The New York Times

Health

WORLD

U.S.

N.Y. / REGION

BUSINESS

TECHNOLOGY

SCIENCE

HEALTH

Report Finds Most Errors at Hospitals Go Unreported

By Robert Pear

Published January 11, 2011

WASHINGTON — Hospital employees recognize and report only one out of seven errors, accidents and other events that harm Medicare patients while they are hospitalized, federal investigators say in a new report.

Yet even after hospitals investigate preventable injuries and infections that have been reported, they rarely change their practices to prevent

repetition of the "adverse events."
Lewenson, inspector general of the
Services.

In the report, being issued on Feb. 1, the inspector general says that a
condition of being paid under Medicare, hospitals recognize errors, some serious
errors and adverse patient events, such as falls, wrong-site surgery,

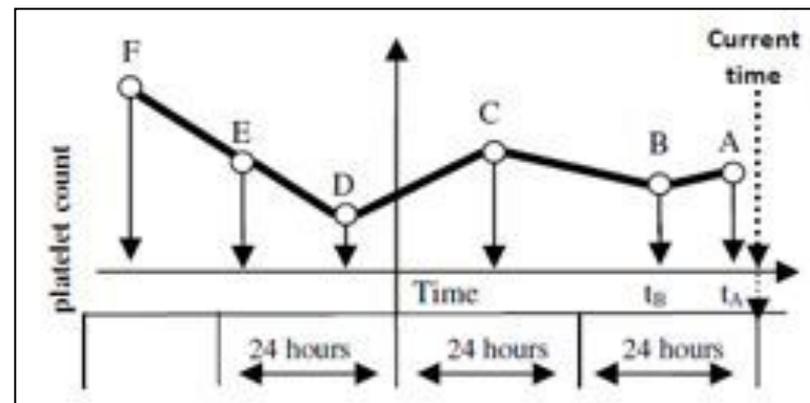
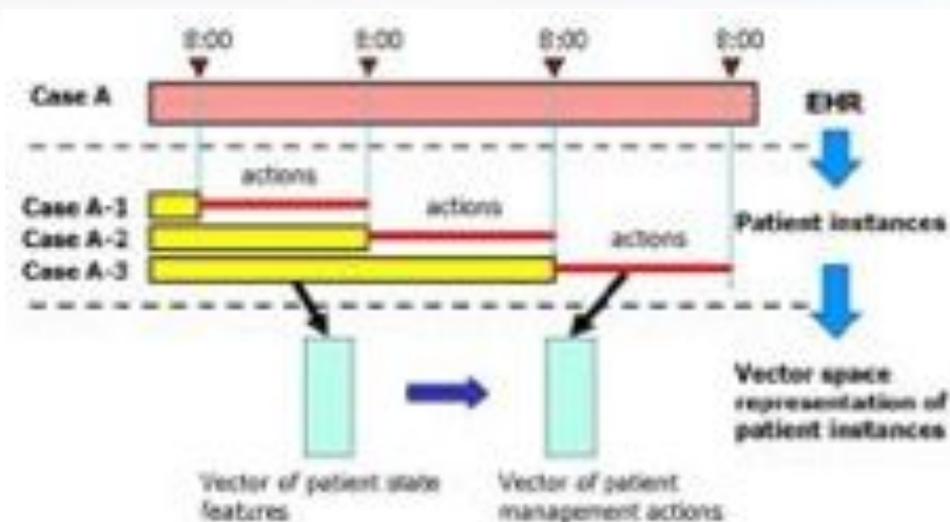
-  Facebook
-  Twitter
-  LinkedIn
-  Print this page
-  Email

**CMS Issues Medicare Final
Payment Rule; Strengthens
Tie Between Payment and
Quality Improvement**

August 2, 2011

Direction: Learn to Detect Anomalies

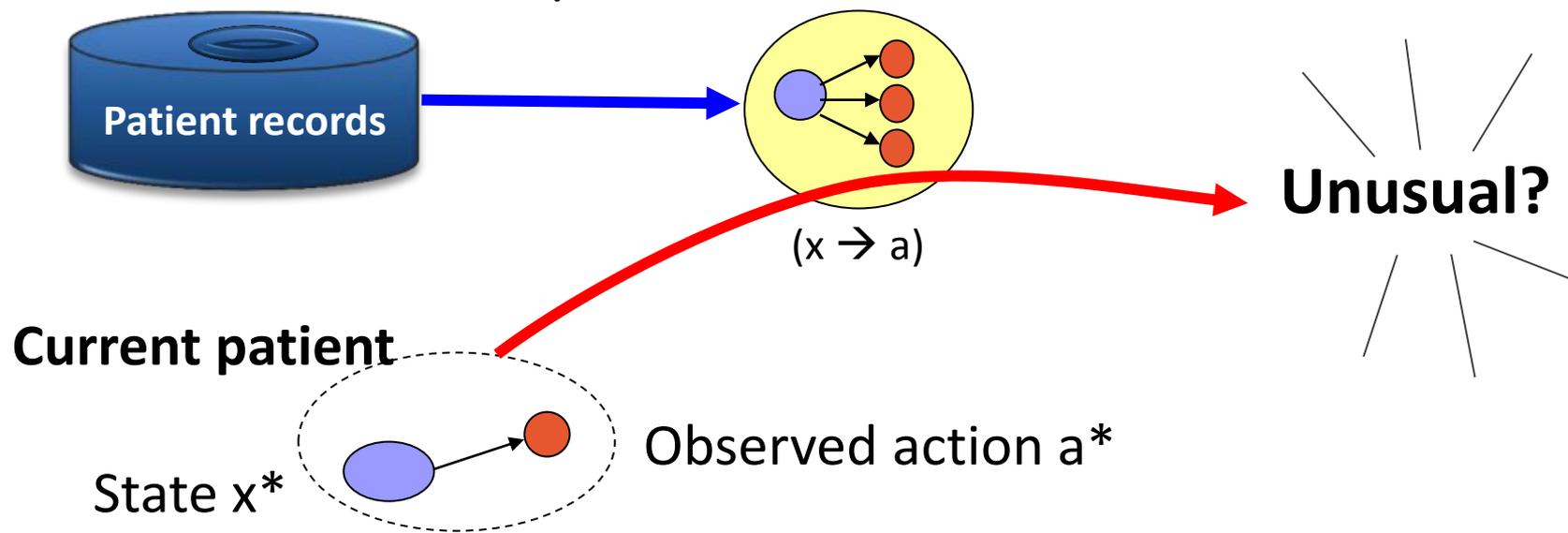
- Identify errors of omission & commission
 - Train on 4,486 cardiac patients; 30,828 episodes



Direction: Learn to Detect Anomalies

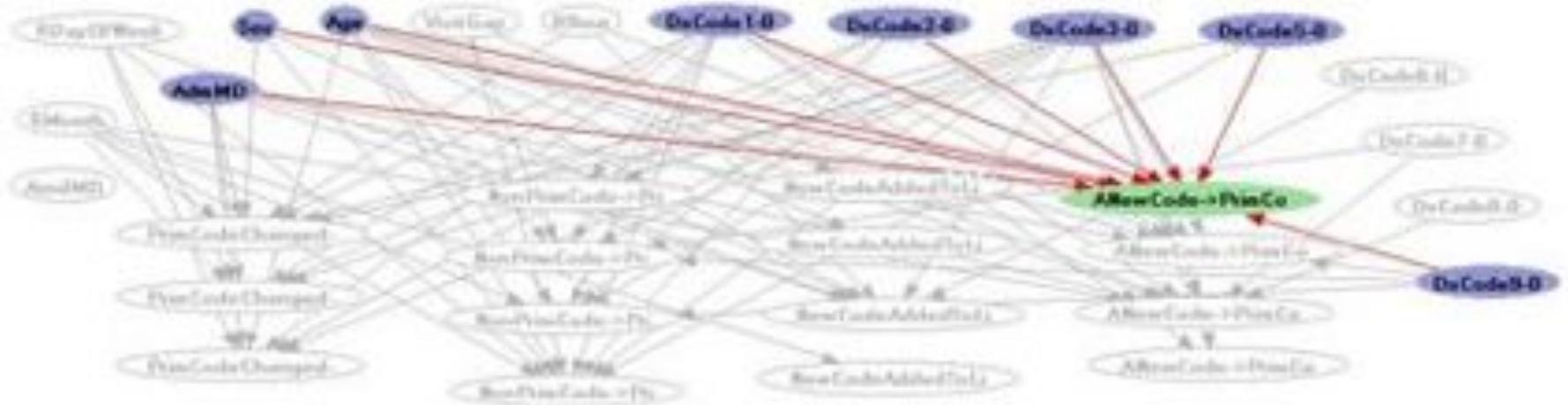
- Identify errors of omission & commission
 - Train on 4,486 cardiac patients; 30,828 episodes

Predictive model:
patient state $x \rightarrow$ actions a



Direction: Forecast Surprises

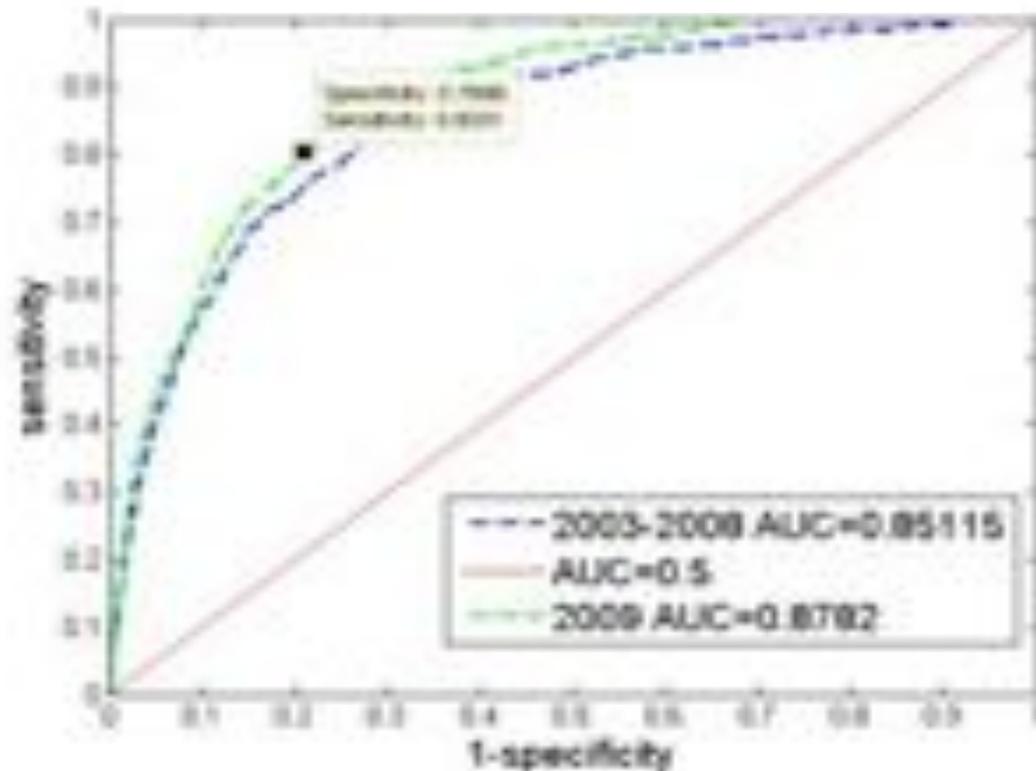
- Infer likelihood that physician will be surprised.
→ Predicts patient will return to ED and be admitted with unforeseen diagnosis.



Direction: Learn to Predict Infection

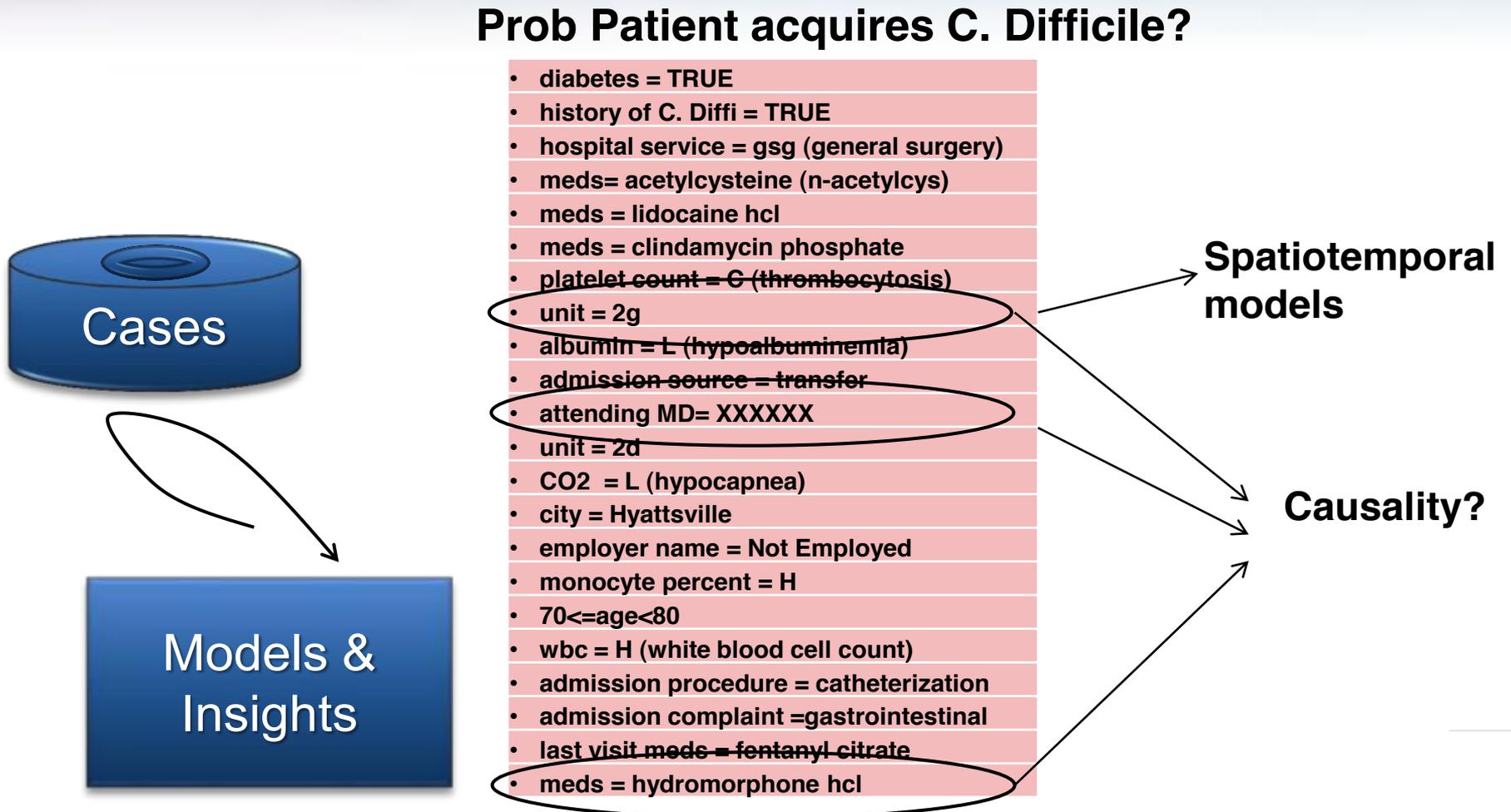
- Healthcare-related infections: 1 in 20 hospital visits
- 5% result in death (top 10 cause of death in US)
- Care costs: ~\$20 billion annually

Predicting MRSA < 48 hrs

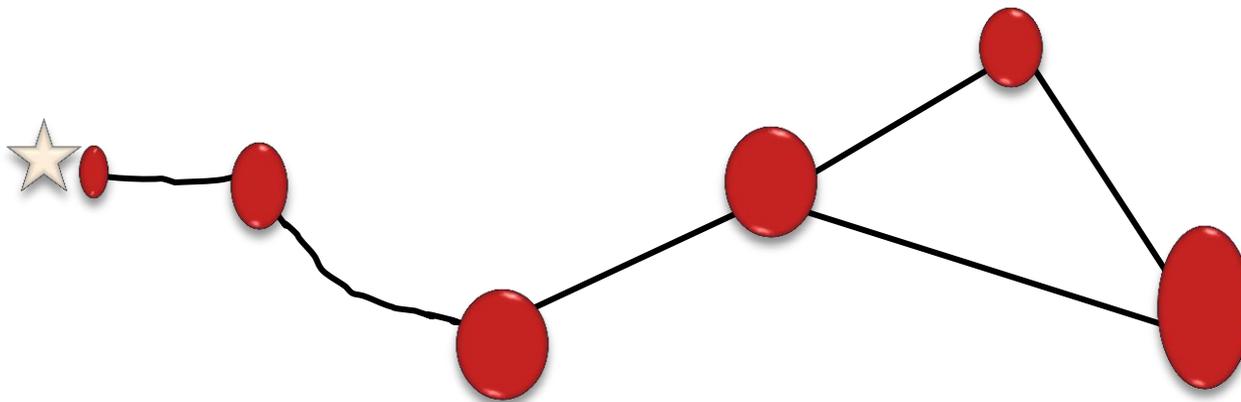
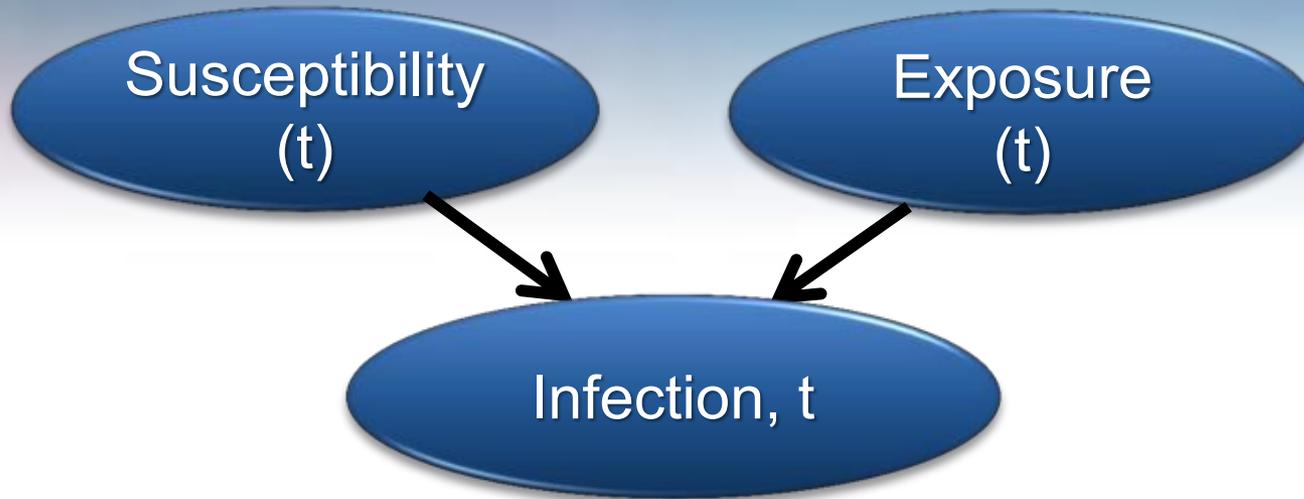


Richer Models & Interventions

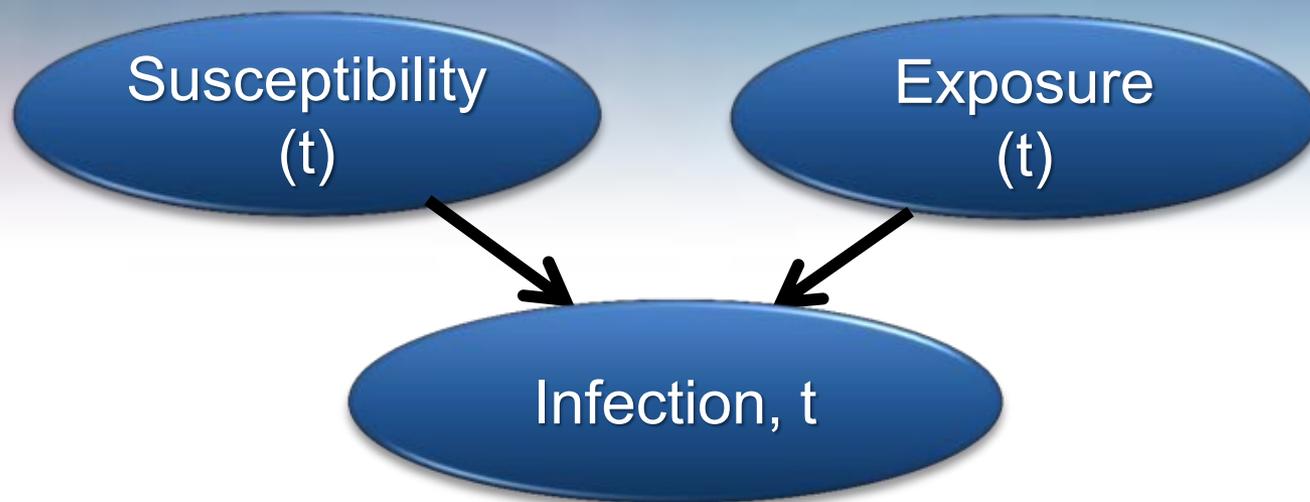
- Insights about deeper mechanisms & causality



Representations of Time and Space

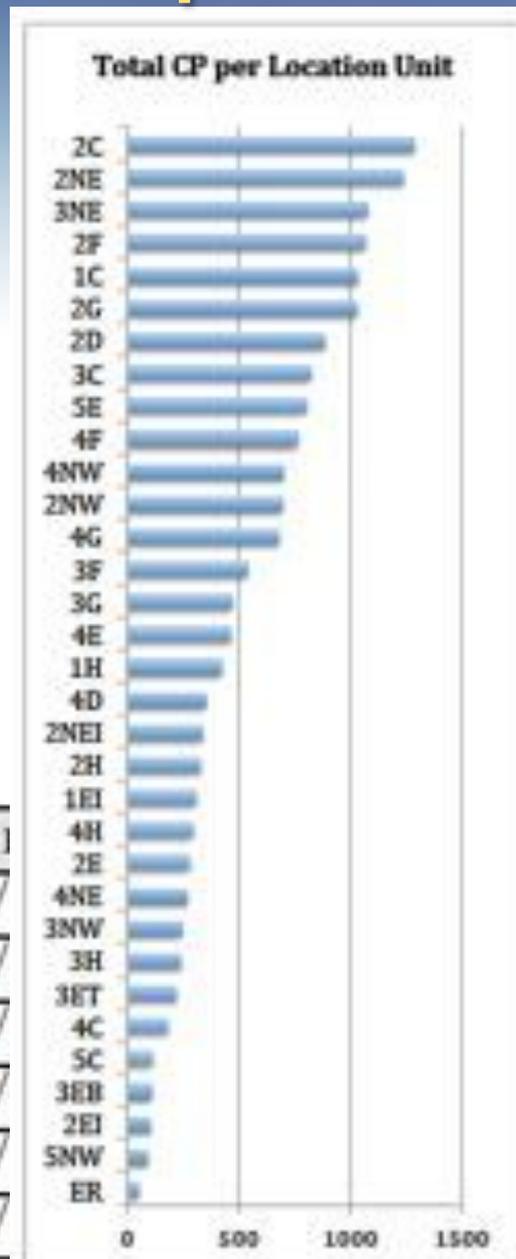


Representations of Time and Space



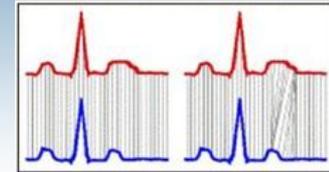
Space & time

| Location Unit, Room | Time |
|------------------------------|-------|
| Cardiac Cath Unit, 4Axx-P | 8/15/ |
| Medicine Patient CU, 4NxxE | 8/15/ |
| Main OR, MRxx-P | 8/17/ |
| Cardiac Intensive CU, CRxx-P | 8/17/ |
| Surgical Patient CU, 4Fxx-B | 8/18/ |
| Surgical Patient CU, 4Fxx-A | 8/24/ |

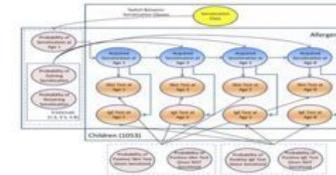


Multiple Advances in Health and CS

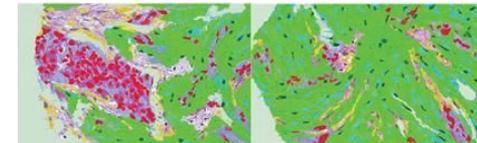
- New pattern recognition methods to predict sudden cardiac death from ECG data.
(Syed, et al. 2011)



- Fusion of immunological & clinical data to elucidate links between environmental exposure and pediatric asthma.
(Simpson, et al. 2010)



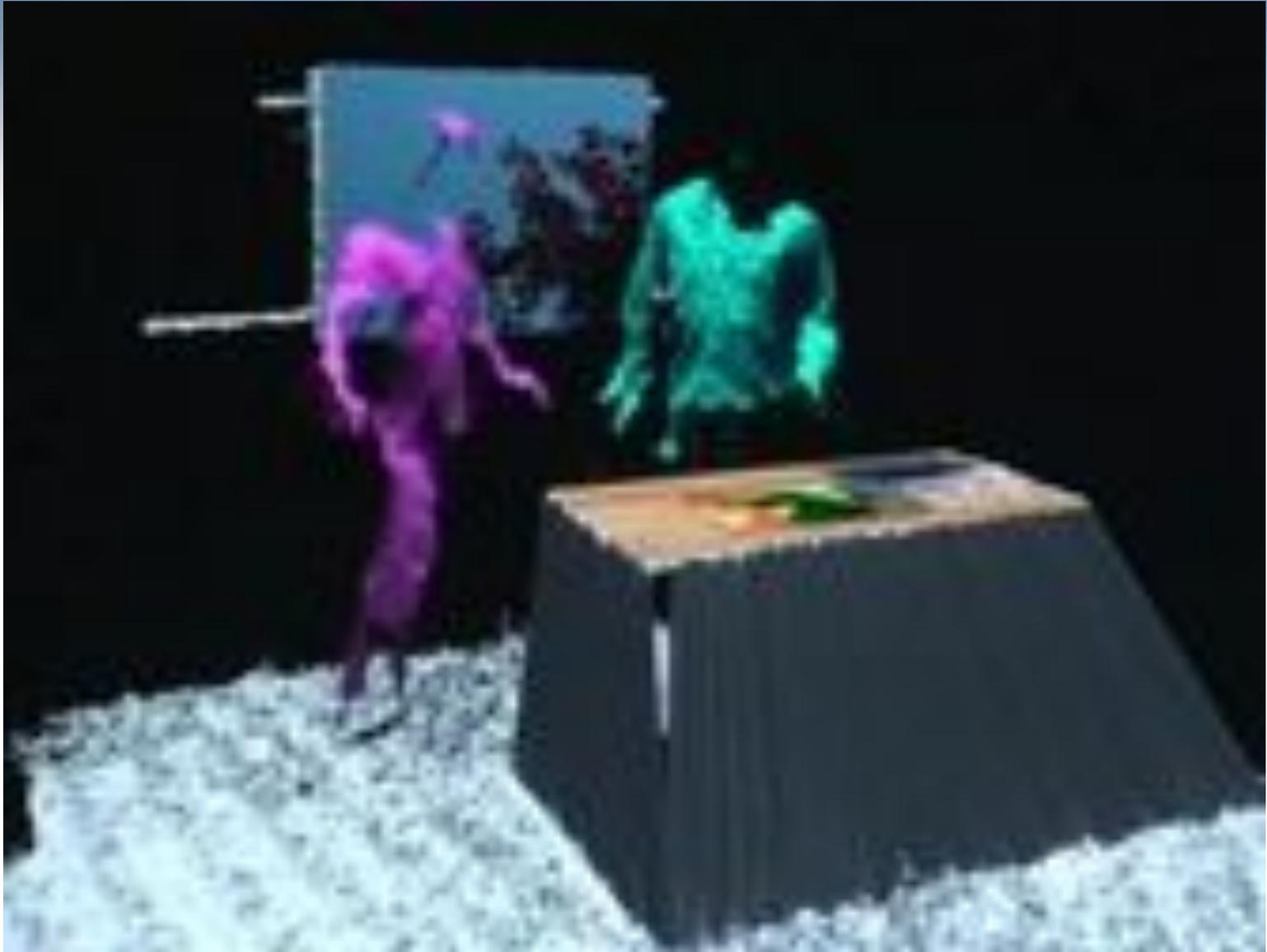
- New image analyses linking histologic features to prognosis in breast cancer.
(Beck, et al. 2011)



- New temporal reasoning to predict NICU outcomes from physiological signals.
(Saria, et al. 2010)



CS Advances and Data Capture in Medicine



Andy Wilson and Hrvoje Benko

CS Advances and Data Capture in Medicine



Research Opportunities Ahead

- Data capture: *workflow, directed vs. ambient, new sources (devices, online activities, etc.)*
- Data sharing and access: *legal, technical*
- Richer models: *time, space, physiology, psychology*
- Causal influences: *from suspicion to cause*
- User modeling: *display, interaction, intention*
- Active learning: *offline & real time*
- Transfer learning: *time & space*
- Fusing genomic, epigenetic, & clinical data

Enabling Evidence-Based Healthcare

- Multiple scientific challenges ahead
- Data capture & availability as key bottleneck
- Criticality of multiple threads of CS research
- Feasibility of enhanced quality at lower cost

On being faithful to the Hippocratic Oath...